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Development Of Water Improvement in The Rural Areas: A Case Study of Bayt Al Faqih District, Hodeidah Governorate, Yemen

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Abstract Water quality study was carried out in ten water sources for domestic purposes of 10 villages from Bayt Al Faqih district. This study aims to evaluate the suitability of groundwater for drinking and domestic purposes. Physical, chemical, and bacteriological parameters of groundwater such as electrical conductivity (EC), pH, total dissolved solids (TDS), Na, K, Ca, Mg, Cl, HCO_3, SO_4, NO_3, F, and fecal coliform were determined. The abundance of the major ions is as follows: Ca > Na > Mg > K and Cl > HCO > SO > NO. The analysis of groundwater samples showed that the water in the study area was alkaline and met the permissible limits for pH, electrical conductivity, total dissolved solids, cations, anions, and total hardness. The samples were suitable for various domestic activities, including drinking.

Before rehabilitation, all groundwater samples were unsuitable for drinking due to the presence of fecal coliform bacteria. However, after rehabilitation, six out of ten villages showed no fecal coliform bacteria, and the remaining four villages experienced a reduction in fecal coliform colonies.

Keywords Water quality, Fecal coliform, Drinking water, Bayt Al Faqih

Introduction

Yemen is the most water-stressed country in the world and one of the ten poorest in terms of available resources. There is limited access to safe water and poor hygiene and sanitation. Access to safe water for domestic use is a pressing issue in Bayt Al Faqih district, located in the Hodiedah governorate of Yemen. The scarcity of safe water sources and inadequate infrastructure pose significant challenges to the local population's health and well-being. According to a report by UNICEF and the World Health Organization (WHO), Yemen is facing one of the world's most severe water crises, with millions of people lacking access to safe drinking water [1].

Contaminated water in developing countries can serve as a medium for the transmission of pathogens such as Rotavirus, Entamoeba histolytica, Campylobacter, E. coli, and other harmful microorganisms, posing a risk of infection to humans [2-4]. Moreover, the presence of E. coli in water serves as a reliable indicator of potential contamination from sewage or animal waste, highlighting the need for thorough water quality assessments and appropriate remedial measures. It is estimated that about 2.3 billion public worldwide are suffering from waterborne diseases [5]. Groundwater is the main source of water for domestic use in Bayt Al Faqih district. However, the groundwater in the region is often contaminated with pollutants and disease-causing microorganisms. The lack of proper sanitation facilities and inadequate waste management systems further contribute to the water quality issues in the district. The improper disposal of sewage and solid waste can contaminate water sources, increasing the risk of waterborne diseases. This issue is highlighted in a report by OCHA (2019) [6], which states that the lack of proper sanitation infrastructure in Yemen poses significant risks to public health. Raising awareness about proper hygiene practices and community participation in water management is essential for sustaining safe water access. Engaging local communities and promoting behaviour change have been recognized as key strategies in addressing water and sanitation challenges in Yemen. Therefore, the provision of safe water for domestic use remains a significant concern in Bayt Al Faqih district, Hodiedah, Yemen. The scarcity of safe water sources, contamination of groundwater, and inadequate sanitation infrastructure pose serious health risks to the local population. However, with collaborative efforts from local authorities, international organizations, and community engagement, it is possible to improve water quality and ensure long-term access to safe water in Bayt Al Faqih district.

One of the major problems facing the efforts to provide access to improved drinking water supplies has been the lack of proper records of available water sources and their hygiene [7]. There is therefore a need for effective studies of the public health effect of provision of a safe drinking water supply for rural communities. The importance of this study is that these studied villages have unimproved and unprotected water sources. These 10 villages located in Bait Al-Faqih district from Hodiedah governorate located 70 km to the south of Hodiedah city as shown in Figure (1). The total population in the study area is 14000 people.

The main objective of this study is to improve the water supply taking into consideration the quality and quantity of water resources and access to safe water in 10 villages from Bayt Al Faqih.

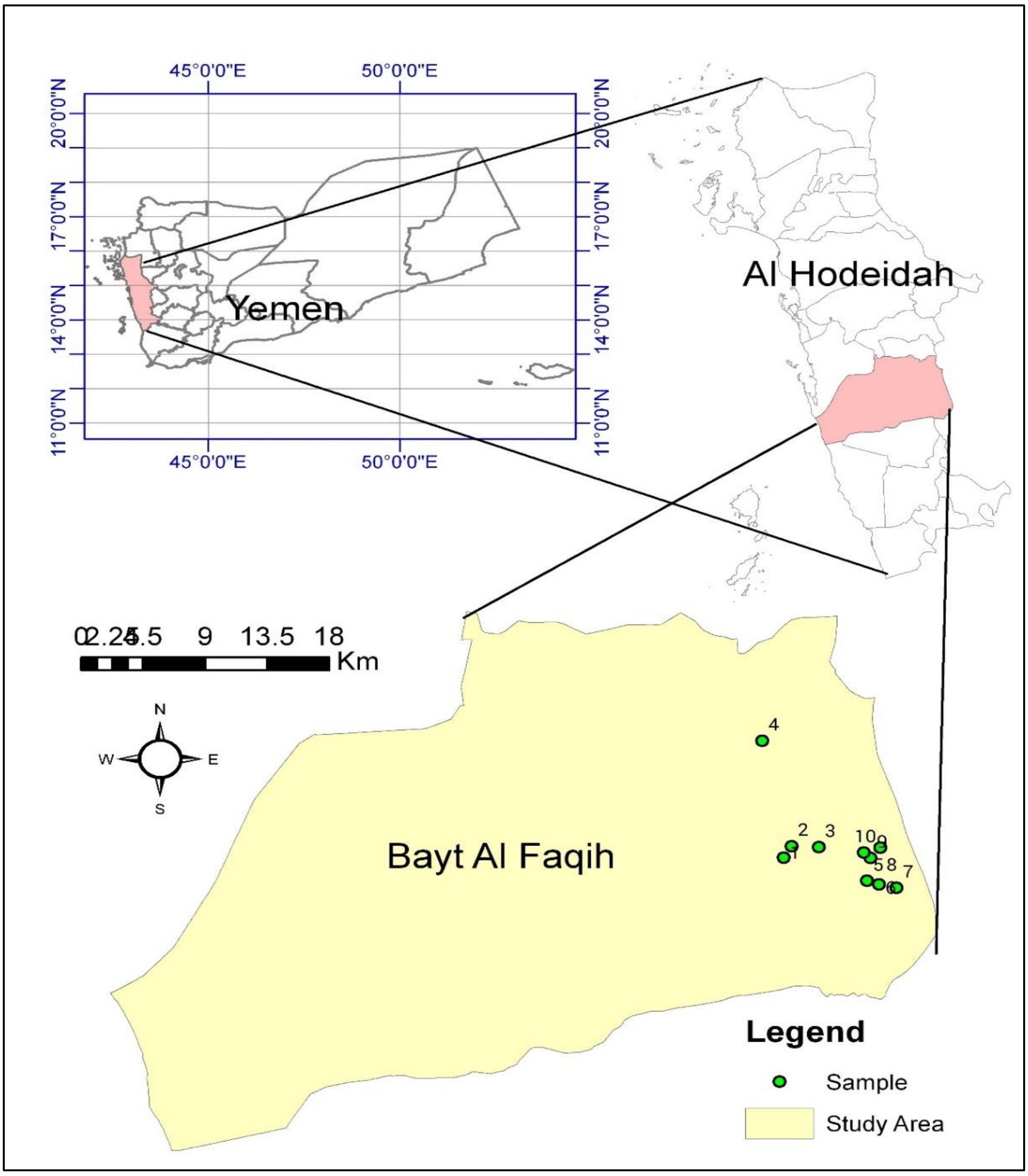

Figure 1: Location map of the study area

Materials and Methods

Water quality analyses for drinking water sources were carried out to ensure the suitability of water sources for domestic purposes to help in the selection of these water sources for rehabilitation work. The water samples from 10 water sources from 10 villages in Bayt Al Faqih district were collected (Fig.1). The bottles were filled after operating the wells of about 2 – 4 hours. The samples were stored in clean polyethylene bottles washed by diluted HCl and washed carefully by distilled water in the laboratory. In the field, the bottles were washed by the sampled water. Adequately labeled and preserved in the refrigerator until analysis.

Direct measurements were made at each site by suitable probes for temperature, electrical conductivity (EC) and pH. In the laboratories of the Faculty of Marine Science at Hodiedah University, the samples were analyzed according to the Standard Methods for the Examination of Water for the ions (Cl, HCO3, SO4, NO3, F, Ca, Mg, Na and K).

Water samples are collected also from all targeted villages for bacteriological monitoring before and after rehabilitation. Fecal coliforms were analyzed using Membrane Filtration technique.

The results of physical, chemical, and bacteriological analyses for water samples were compared with Yemeni standards for drinking purposes and WHO standards.

Focus Group Discussion FGD and Key Informal Interview KII for 120 Household HH are also used as collection tools to study and evaluate the impact of water source rehabilitation intervention in the study area.

Results and Discussion

Water sources

The results show that the water sources for domestic use in studied areas in Bayt Al Faqih district have undergone changes in terms of their types and availability before and after rehabilitation efforts as shown in Fig. (2). The main water sources can be categorized into three types: boreholes supplied with motorized pump, open-dug well, and water supply network.

Before rehabilitation, 63 households (53%) relied on boreholes supplied with motorized pumps as their main water source. This indicates that a significant portion of the population depended on groundwater extracted through boreholes using motorized pumps. After rehabilitation efforts, the number of households relying on this water source increased to 77 (64%), suggesting an improvement in the availability or functionality of boreholes with motorized pumps. Whereas 22 households (18%) had access to water through the water supply network and after rehabilitation efforts, the number of households connected to the water supply network increased to 43 (36%), indicating an expansion in access to treated water through a centralized system.

Before rehabilitation, 35 households (29%) relied on open-dug wells as their main water source. Open dug wells are traditional water sources where the water is manually extracted by digging into the ground. However, after rehabilitation efforts, the number of households depending on open-dug wells dropped to zero. This suggests that rehabilitation works may have focused on replacing or improving open-dug wells to provide alternative or more reliable water sources.

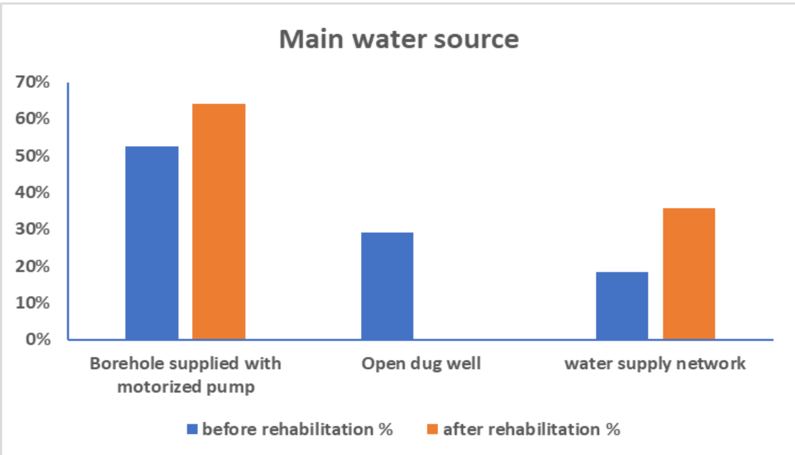

Figure 2: water sources type in the study areas.

The rehabilitation efforts have resulted in notable changes in the availability and types of water sources for domestic use in the studied areas. There has been an increase in the reliance on boreholes with motorized pumps, suggesting improvements in groundwater extraction and supply. The elimination of open dug wells as a water source indicates efforts to replace or improve them with more reliable alternatives. The increase in households connected to the water supply network signifies progress in expanding access to safe water supply.

Physico – Chemical parameters of water sources:

The results of the analysis of the groundwater samples are presented in Table (1). The pH values of groundwater samples range from 7.2 to 8.4 with an average value 7.8, This shows that the groundwater in the study area is mainly alkaline in nature. Electrical conductivity (EC) indicates the amount of materials dissolved in water and the values of the studied samples range from 545 µS/cm to 2006 µS/cm with an average value 1096 µS/cm. TDS ranges from 327 mg/l to 1304 mg/l. Water resources in the study area are freshwater type. Freshwater has TDS of less than 1000 mg/l [8]. Approximately all studied samples have TDS less than 1000 mg/l except one sample (Al-zamboliah Al-Janobiah) slightly greater than 1000 (Fig. 3). All of the TDS values obtained in the study area are within the permissible limits according to the Yemeni Standard, making the water suitable for various domestic activities.

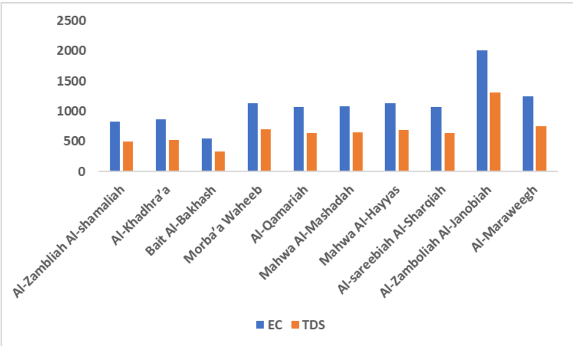

Figure 3: EC in µS/cm and TDS in mg/l for the studied samples.

Table (1): Physical, Chemical, and biological characteristics of studied samples.

Sample #	Village	pH	EC	TDS	Na	K	Ca	Mg	Cl	HCO3	SO4	NO3	F	TH	Fecal coliform colonies/100ml	
															Before Reh.	After Reh.
1	Al-Zambliah Al-shamaliah	7.9	821	493	56	0.7	90	15	71	140	90	29	Nil	287	30	Nil
2	Al-Khadhra'a	7.8	858	515	68	0.93	112	25	71	165	100	29	Nil	383	>100	Nil
3	Bait Al-Bakhash	8.4	545	327	61	0.76	25	11	71	45	130	10	Nil	108	>100	15
4	Morba'a Waheeb	7.9	1130	698	78	1.02	109	17	71	140	180	19	Nil	343	>100	10
5	Al-Qamariah	7.6	1068	641	59	0.96	88	16	92	185	160	20	Nil	286	85	Nil
6	Mahwa Al-Mashadah	7.7	1081	649	66	0.8	85	104	92	145	110	21	Nil	641	>100	Nil
7	Mahwa Al-Hayyas	7.52	1136	682	72	1	114	12	71	170	170	17	Nil	334	>100	10
8	Al-sareebiah Al-Sharqiah	7.4	1066	640	67	0.98	102	10	71	140	240	21	Nil	296	50	15
9	Al-Zamboliah Al-Janobiah	7.2	2006	1304	329	2.34	231	36	350	140	240	46	Nil	726	30	Nil
10	Al-Maraweegh	8.1	1250	750	82	1.1	107	14	113	236	165	38	Nil	325	>100	Nil

Among the cations, the concentrations of Na, K, Ca, and Mg ions ranged from 56 to 326, 0.7 to 2.34, 25 to 231 and 10 to 104 mg/l with a mean of 94, 1.1, 106 and 26 mg/l, respectively (Fig. 4a). The order of abundance is Ca > Na > Mg >> K. Among the anions, the concentrations of Cl, HCO_3, SO_4 and NO_3 lie between 71 to 350, 45 to 236, and 90 to 240 with a mean of about 107, 150, 158 and 25 mg/l in respective order Fig. (4b). The order of abundance of major anions is SO_4 >HCO_3 > Cl. All studied samples fall within the maximum permissible limit for drinking purposes as per the Yemeni and WHO standards [9-10].

The high concentration of nitrate in drinking water is toxic and causes blue-baby disease/ methemoglobinemia in children and is responsible for an increased risk of developing stomach and intestinal cancer if consumed for long periods [11-12]. The Yemeni Standard of Drinking Water has set 10 mg/l to 50 mg/l for Nitrate. High concentrations of nitrate in water can probably be due to poor sanitation and latrine construction, fertilizer, and other agrochemical use. The nitrate concentrations range from 10 to 46 mg/l which fall within the permissible limit of Yemeni and WHO standards.

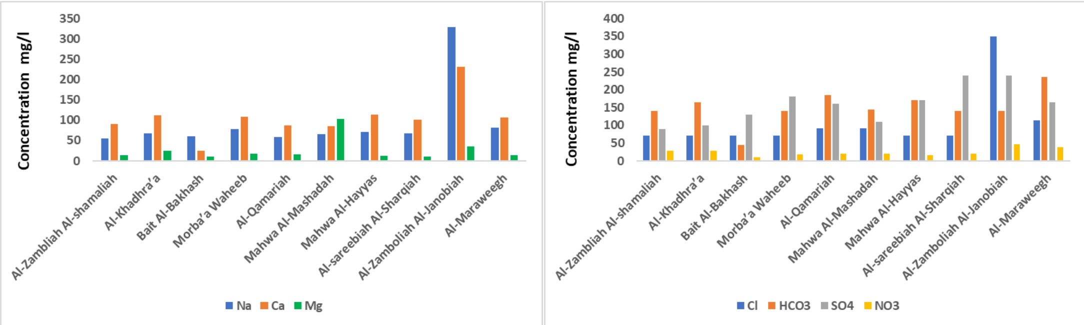

Figure 4: Ions concentration in mg/l (a) Na, Ca, Mg and (b) Cl, HCO_3, SO_4 and NO_3

Total hardness is determined by the amount of calcium and magnesium in a particular water sample. Their high concentrations are generally not a health concern but a guideline value of 200mg/l is set by WHO, (2017). This may be due to an inverse relationship that exists between cardiovascular disease and water hardness, with increased risk occurring with Calcium concentrations less than 60 mg/L [13-14]. In large concentrations, they may also affect the taste of the water which also leads to soap wastage if the water is used for washing [15]. The TH values range from 220 as mg $CaCO_3$ /l to 482 with an average value of 354. The classification of groundwater based on TH shows that the majority of samples fall in the very hard category except three samples fall within the hard type [16]. According to WHO (2017) and Yemeni standards (2000), most groundwater samples fall within the maximum permissible limit for drinking.

Water Quality Index:

Different WQI models have been created and used globally in recent years to assess the quality of surface and groundwater. The literature shows that the WQI model is one of the most efficient rating methods, which is used for scaling and quality assessment of water [17-18]. WQI was calculated by using the given weighted arithmetic index technique to evaluate the suitability of groundwater in the study area for drinking purposes using WHO (2017). Eleven parameters (pH, TDS, bicarbonate, chloride, Sodium, Calcium, potassium, Magnesium, nitrates, fluoride, and sulphate) were used. To compute WQI four steps are followed by Gebrehiwot et al. (2011) [19]. In the first step, each of the 11 parameters has been assigned a weight (wi) according to its relative importance in the overall quality of water for drinking purposes [19-20] (Table 2). In the second step, the relative weight (Wi) is computed using a weighted arithmetic index method given below [21-23] in the following steps.

$$\mathcal{W}i = \frac{wi}{\sum_{i=1}^{n} wi} \;\; \text{.........} \;\; (1)$$

Where Wi is the relative weight, wi is the weight of each parameter and n is the number of parameters.

In the third step, a quality rating scale (Qi) for each parameter is assigned by dividing its concentration in each water sample by its respective standard according to the guidelines of WHO (2017) and then multiplied by 100:

Qi = (Ci / Si) x 100 …… (2)

where Qi is the quality rating, Ci is the concentration of each chemical parameter in each water sample in mg/l, and Si is the WHO drinking water standard for each chemical parameter in mg/l according to the guidelines of WHO (2017) (Table 3). In the fourth step, the SI is first determined for each chemical parameter, which is then used to determine the WQI as per the following equation:

SIi = Wi x Qi…………………………… (3)

SIi is the sub index of the ith parameter and Qi is the rating based on the concentration of the ith parameter.

The overall Water Quality Index (WQI) was calculated by adding together each sub index value of each groundwater sample as follows:

WQI = ∑SIi…………………………… (4)

Computed WQI values are usually classified into five categories (Table 3): excellent, good, poor, very poor, and unfit water for drinking purposes [24 - 25].

Table 2: WHO Standards, weight (wi) and calculated relative weight (Wi) for each parameter

Chemical parameter	WHO 2017	Wight Wi	Relative weight Wi
pH	8.5	3	0.0882
TDS	500	5	0.1471
HCO3	300	2	0.0588
Cl	250	3	0.0882
NO3	45	5	0.1471
K	12	1	0.0294
Na	200	3	0.0882
Mg	50	2	0.0588
Ca	75	2	0.0588
F	1	5	0.1471
SO4	250	3	0.0882

Table 3: Classification of computed WQI values for human consumption

WQI range	**Type of water**
< 50	Excellent water
50.1 - 100	Good water
100.1 - 200	Poor water
200.1 - 300	Very poor water
> 300	Unfit for drinking

Quality rating (Qi), Sub index of each chemical parameter (SIi), WQI and water classification of each water sample of the study area.

The water quality index of the samples analyzed varied between 35.7 and 121.9, as indicated in Table (4). Out of the total samples, 80% were classified as good water, representing eight samples. One sample, accounting for 10%, was classified as excellent water, while only one sample, or 10%, fell under the category of poor water.

Table 4: Quality rating (Qi), Sub index of each chemical parameter (SIi), WQI and water classification of water samples of the study area.

Sample #	pH		TDS		HCO3		Cl		NO3		K		Na		Mg		Ca		F		SO4		WQI	WQI classification
	Qi	Sli	Qi	Sli	Qi	Sli	Qi	Sli	Qi	Sli	Qi	Sli	Qi	Sli	Qi	Sli	Qi	Sli	Qi	Sli	Qi	Sli		
1	92.9	8.2	98.6	14.5	46.7	2.7	28.4	2.5	64.4	9.5	5.8	0.2	28.0	2.5	30.0	1.8	120.0	7.1	0.0	0.0	36.0	3.2	52.1	Good water
2	91.8	8.1	103.0	15.1	55.0	3.2	28.4	2.5	64.4	9.5	7.8	0.2	34.0	3.0	50.0	2.9	149.3	8.8	0.0	0.0	40.0	3.5	56.9	Good water
3	98.8	8.7	65.4	9.6	15.0	0.9	28.4	2.5	22.2	3.3	6.3	0.2	30.5	2.7	22.0	1.3	33.3	2.0	0.0	0.0	52.0	4.6	35.7	Excellent water
4	92.9	8.2	139.6	20.5	46.7	2.7	28.4	2.5	42.2	6.2	8.5	0.3	39.0	3.4	34.0	2.0	145.3	8.5	0.0	0.0	72.0	6.4	60.8	Good water
5	89.4	7.9	128.2	18.9	61.7	3.6	36.8	3.2	44.4	6.5	8.0	0.2	29.5	2.6	32.0	1.9	117.3	6.9	0.0	0.0	64.0	5.6	57.4	Good water
6	90.6	8.0	129.8	19.1	48.3	2.8	36.8	3.2	46.7	6.9	6.7	0.2	33.0	2.9	208.0	12.2	113.3	6.7	0.0	0.0	44.0	3.9	65.9	Good water
7	88.5	7.8	136.4	20.1	56.7	3.3	28.4	2.5	37.8	5.6	8.3	0.2	36.0	3.2	24.0	1.4	152.0	8.9	0.0	0.0	68.0	6.0	59.0	Good water
8	87.1	7.7	128.0	18.8	46.7	2.7	28.4	2.5	46.7	6.9	8.2	0.2	33.5	3.0	20.0	1.2	136.0	8.0	0.0	0.0	96.0	8.5	59.5	Good water
9	84.7	7.5	260.8	38.4	46.7	2.7	140.0	12.4	102.2	15.0	19.5	0.6	164.5	14.5	72.0	4.2	308.0	18.1	0.0	0.0	96.0	8.5	121.9	Poor water
10	95.3	8.4	150.0	22.1	78.7	4.6	45.2	4.0	84.4	12.4	9.2	0.3	41.0	3.6	28.0	1.6	142.7	8.4	0.0	0.0	66.0	5.8	71.3	Good water

Bacteriological characteristics:

Bacterial contamination of drinking water is a major contributor to water-borne diseases in rural areas of most developing countries where water sources are communally shared [26-27] and exposed to multiple fecal-oral transmission pathways in their neighborhood boundaries [28-29]. The World Health Organization (WHO) estimates that diarrhoeal disease due to exposure to unsafe drinking water, inadequate sanitation, and hygiene practices contribute to more than 25% of the reported global environmental burden of the disease [30]. Given this status, highly effective interventions for the prevention and control of E. coli contamination of water sources are essential. The results of bacteriological characteristics are presented in Table (1). All water samples contained fecal coliform indicating a contamination of water sources. The fecal coliform counts ranged from 20 to more than 100. According to WHO (2017) and the Yemeni standards for drinking water the count of the fecal coliform bacteria must be zero in 100 ml. From the results of this study, it was found all the groundwater samples are not suitable for drinking purposes before rehabilitation. Therefore, it is necessary to encourage water source rehabilitation and protection before using it for domestic purposes.

The results for the villages tested after rehabilitation are shown in Table 1. The rehabilitation project involved fixing wells, improving sanitation infrastructure, and educating people about hygiene practices. The results show that six villages out of ten had no fecal coliform after rehabilitation, whereas four villages had a reduction in fecal coliform colonies after the project (Table 1 and Fig 6).

Overall, the results suggest that the water rehabilitation project had a mixed impact on the water quality in the villages tested. More work is needed to ensure that all of the villages have safe drinking water.

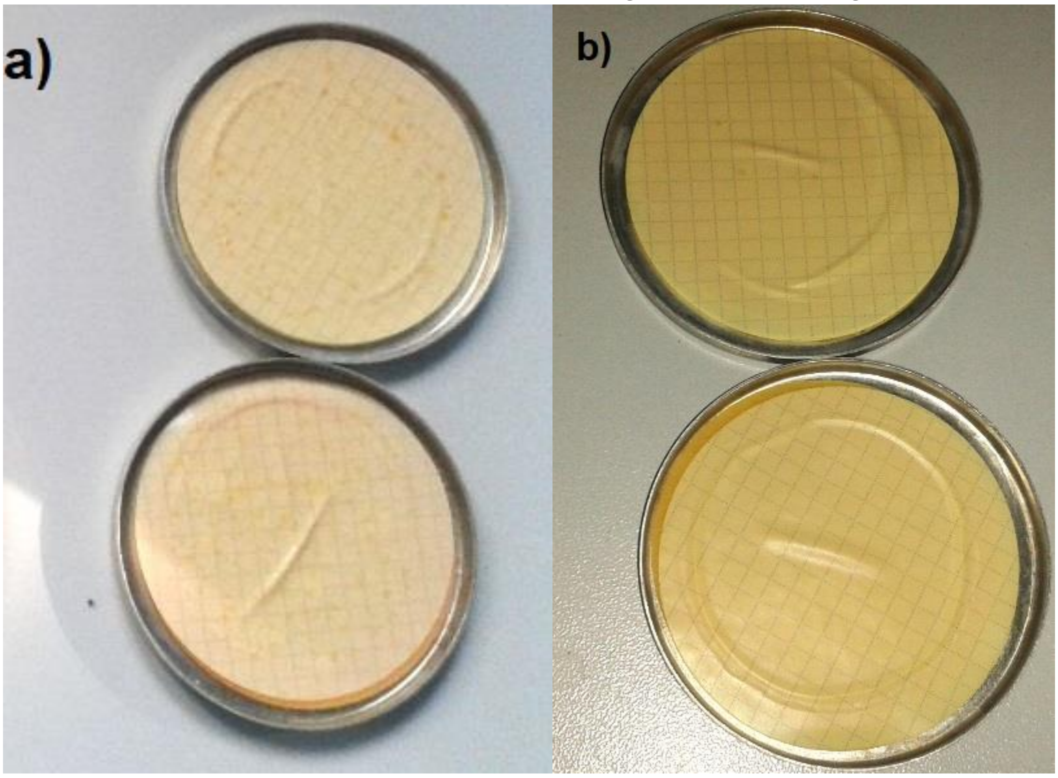

Figure 5: Fecal coliform counts a) before rehabilitation and b) after rehabilitation

Focus Group Discussion and Key Informant Interview:

The results of FGD show that the primary water source for all participants was a borehole supplied with a motorized pump. As an alternative source, some participants collected water from dug wells and private farms but sometimes they were not available due to a shortage of diesel.

Waiting Time: Before rehabilitation, participants had to wait in queues for at least three hours due to crowding and water scarcity. However, with the installation of multiple taps at the water point, the waiting time has significantly decreased, allowing children to spend less time collecting water and attending school.

Quantity of Water: In terms of water availability in the households per day, both for drinking and domestic use data analysis after the rehabilitation survey shows that, the average amount of water collected per household per day is 160 liters for drinking water and other household purposes. Also, It is found that 17% (20) consumed less than 15 liters/person/day which is below the standard, 84 % (100) respondent households had access to 15 or more liters per person per day.

Water Treatment: Approximately 50% of respondents reported some form of water treatment. Among those treating the water, the majority (80%) used filtration, while a small percentage boiled the water (12%) or used ceramic filters (8%). Participants mentioned that water filtration was rarely used during dusty weather.

Hygiene Awareness: All participants attended hygiene awareness programs conducted in association with rehabilitation works and expressed satisfaction, noting that it had brought about positive changes within their communities.

Water Source Rehabilitation: Participants expressed happiness with the rehabilitation of the water source. They mentioned that before rehabilitation, there were issues with water scarcity and poor water quality. After rehabilitation, the water became more sufficient and clear.

Overall, the rehabilitation works improved access to water, reduced waiting times, increased water quality, and promoted hygiene awareness among the communities.

Conclusion

The study conducted in the Bayt Al Faqih district examined changes in water sources for domestic use before and after rehabilitation efforts. Before rehabilitation, the main water sources were boreholes with motorized pumps, open-dug wells, and the water supply network. After rehabilitation, there was an increase in households relying on boreholes with motorized pumps and an expansion in access to the water supply network. Open-dug wells were eliminated as a water source, indicating efforts to replace or improve them.

The analysis of groundwater samples showed that the water in the study area was alkaline and met the permissible limits for pH, electrical conductivity, total dissolved solids, cations, anions, and total hardness. The samples were suitable for various domestic activities, including drinking.

Before rehabilitation, all groundwater samples were unsuitable for drinking due to the presence of fecal coliform bacteria. However, after rehabilitation, six out of ten villages showed no fecal coliform bacteria, and the remaining four villages experienced a reduction in fecal coliform colonies.

Overall, the rehabilitation works improved access to water, reduced waiting times, increased water quality, and promoted hygiene awareness. These findings emphasize the importance of water source rehabilitation and protection for safe and sufficient water supply in similar communities.

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